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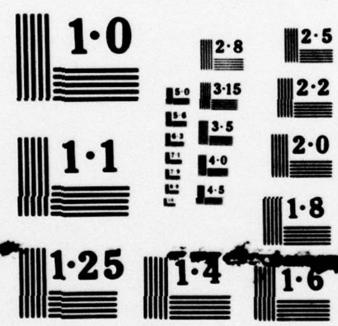

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Geomonitor, in addition to analyzing vertical and backscatter digital ionograms, digitizes magnetometer, riometer, radio polarimeter, and satellite scintillation data for transmission to the using site. Compression of the digital ionogram data and the other geophysical and ionospheric data permits transmission over a 600-1200 baud telecommunications link to the GDS. The GDS formats and displays the data for the remote observer and analyzes the data to call attention to disturbances. For each ionogram, lines are printed summarizing the frequency extent of the observed echoes and the variation with height or range of the echo amplitudes. As further data arrive, lines are added to the printouts, resulting in time histories, so-called " ionospheric characteristics" of layer heights, backscatter ranges and critical or top frequencies. In addition to showing regular diurnal variations, the onset, type, and severity of ionospheric disturbances can be determined from these characteristics. To aid in the interpretation of the characteristics, ionograms are reconstituted from the ionospheric data messages. These with displays of the other geophysical and ionospheric data create a comprehensive display for evaluation by the observer.

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REMOTE IONOSPHERIC MONITORING

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ABSTRACT

A program for the development of automatic real-time monitoring of the ionosphere at a remote observing location is described. The Digisonde 128, a digital sounder in routine operation since 1970, provides digital data suitable for online computer processing. Analytical methods for the detection of ionospheric echoes and the determination of their virtual height, amplitude, and range spread have been developed. For real time application, these methods have been implemented in hardware using microprocessors. The Geomonitor and Geomonitor Display System (GDS) provide the capacility to perform the monitoring at any desired site separated from the remote observing location. The Geomonitor, in addition to analyzing vertical and backscatter digital ionograms, digitizes magnetometer, riometer, radio polarimeter, and satellite scintillation data for transmission to the using site. Compression of the digital ionogram data and the other geophysical and ionospheric data permits transmission over a 600-1200 baud telecommunications link to the GDS. The GDS formats and displays the data for the remote observer and analyzes the data to call attention to disturbances. For each ionogram, lines are printed summarizing the frequency extent of the observed echoes and the variation with height or range of the echo amplitudes. As further data arrive, lines are added to the printouts, resulting in time histories, so-called "ionospheric characteristics" of layer heights, backscatter ranges and critical or top frequencies. In addition to showing regular diurnal variations, the onset, type, and severity of ionospheric disturbances can be determined from these characteristics. To aid in the interpretation of the characteristics, ionograms are reconstituted from the ionospheric data messages. These with displays of the other geophysical and ionospheric data create a comprehensive display for evaluation by the observer.

INTRODUCTION

The high latitude ionosphere, strongly controlled by auroral particle precipitation and especially disturbed during auroral substorms, affects a variety of USAF and DOD systems, as well as military and commercial communications links operating in this environment. To advise the various military users of prevailing conditions, the AF Air Weather Service (AWS) has monitored routinely the state of the local arctic ionosphere and the onset of disturbances from various ground sites as among others Goose Bay, Labrador, Eielson AFB, Alaska, Tromso, Norway. The reports are collected and evaluated by the AF Global Weather Central (AFGWC) and advisories and warnings are being disseminated routinely or on special request through the Space Environment Support System (SESS).

The monitoring of this environment has for a long time been accomplished by trained personnel through hourly reports from the various sites, using a limited selection of geophysical parameters. To automate the process of data analysis and data transmission especially at remote sites, we have developed the Geomonitor (Reinisch and Smith, 1976). This system extracts the essential information from the digital

ionograms, supplied by the Digisonde (Bibl et al, 1970; Bibl and Reinisch, 1978), a digital ionosonde used for vertical incidence and backscatter soundings. Together with properly formatted digitized data from other geophysical sensors messages are formed that can be sent to Air Force Global Weather Central or to other user sites as a final step to remotely monitor the environment of interest. This remote monitoring capability is of special interest at high latitudes, since a.) the auroral effects routinely and severely disturb the ionospheric environment making 24 hour coverage and fast issue of warnings essential, b.) rapdily rising manpower costs and the difficulty to find qualified personnel willing to work for extended periods at these remote, high latitude stations require automation as a cost effective solution.

GOOSE BAY OVAL MONITOR STATION

Requirements for better specifications of the high latitude ionospheric and auroral environment surfaced in the mid- to late sixties, as AF surveillance systems increased their accuracy requirements, the use of an Over-the-Horizon Backscatter System in these disturbed regions began to be contemplated and effects on trans-ionospheric propagation started to become a major concern. AFGL started a large airborne program to improve the understanding of the structure and dynamics of the high latitude ionosphere. Flights between 1967 and 1971 indicated that the auroral oval concept (Feldstein and Starkov, 1967) provided a good ordering frame for various ionospheric phenomena. Airborne investigations of initially the noon sector of the oval (Whalen et al, 1971) and then the more disturbed and complicated night sector (Buchau et al, 1972; Wagner and Pike, 1972) led to a unified picture of the structure of the high latitude environment (Gassmann, 1972) and suggested the feasibility of monitoring this environment from a few selected points. To illustrate the concept, we show in Figure 1 the auroral oval (shaded area) for average magnetic conditions and the location of Goose Bay in relation to the oval in hourly increments. Large scale ionospheric entities ordered by the auroral oval are: a. The FLIZ (F-layer irregularity zone, Pike, 1972) generally colocated with the oval belt, b. The midlatitude F-layer trough (Muldrew, 1965) found south of the equatorward boundary of the night sector of the oval, c. Auroral Es, colocated with the oval belt, d. Auroral E, a particle produced thick E-layer belt coinciding with the oval in the night sector and found just south of the oval in the noon sectors, and e. D region enhancements, during substorms within the night sector, of the oval, and traveling through sunrise around the oval into the noon sector of the oval, where they arrive in a region between 60° and 70° corrected geomagnetic (CG) latitude within .5 to 2 hours after the onset of the substorm (Driatskiy, 1968; Elkins, 1972) and f. The polar cap ionosphere within the oval belt, with auroral, E-layer and F-region phenomena different from those in the adjacent oval. The diameter of the auroral oval and the auroral activity within the oval belt and the polar cap are under strong control of the interplanetary and the earth magnetic field. The equatorward edge of the midnight sector of the oval is found at 70° (CG) latitude under quiet (Q=0) conditions and at 59° CG latitude under very disturbed (Q=8) conditions. All the described ionospheric regimes and phenomena change their locations and/or their intensities as the oval expands or contracts.

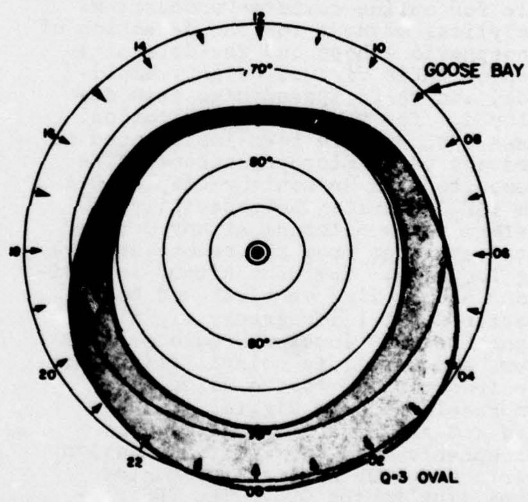

Figure 1 shows the auroral oval in a CG latitude-local time coordinate system. Goose Bay, located at 65° CG latitude, becomes an auroral oval station from 22:30 to 03:30 CGLT. During the other hours of darkness it is an F-layer trough station while in daytime it is between 500 to 1000 km to the south of the equatorward edge of the oval. While under the auroral oval, vertical incidence soundings, and riometer and magnetometer measurements allow the assessment of the state of the auroral ionosphere and the determination of the onset time and severity

of auroral disturbances. In the afternoon and evening hours, backscatter soundings directed towards the oval edge show strong irregularities which are associated with the aurora (Wagner and Pike, 1972) and thus permit the determination of the oval diameter many hours prior to the time, the oval moves over the station. In the early morning and pre-midday hours, Goose Bay is under the influence of the previously mentioned eastward drifting D-region enhancements associated with auroral substorms and monitoring of the existence of auroral disturbances in the midnight sector is possible for many hours.

Based on the evolving monitoring concepts the Air Force Geophysics Laboratory (AFGL) established in 1971 the Goose Bay Ionospheric Observatory. The station was equipped with riometers, magnetometers, satellite receivers for total electron content measurements, and a Digisonde 128 alternatingly connected to two separate transmitting antennas for vertical incidence and backscatter soundings. The Digisonde is a step frequency sounder with a 0.25 to 16 MHz frequency range. Phase coding and coherent integration are used to increase the signal-to-noise ratio. Envelope detection, i.e. power integration, is applied for backscatter soundings, since scatter type reflections or reflections from moving ionization fronts result in random or continuous (Doppler shift) phase changes, respectively, incompatible with a coherent integration scheme.

The two logarithmically compressed quadrature samples are integrated in 128 equidistantly spaced range bins (with selectable ΔZ) determining the amplitude with 6 bit resolution and the phase with 3 bits. The data are recorded on digital magnetic tape and, using an optically weighted font, are printed out on paper. Using available telecopier techniques the digital ionograms can be transmitted via telephone line to any other location for real time assessment of ionospheric conditions at Goose Bay.

Figure 2 shows in its left part a typical daytime ionogram obtained by the Goose Bay Digisonde. For each 1 MHz frequency band, shown between two frequency marks, 2160 characters of amplitude, phase and housekeeping (date-time-frequency, etc.) information is recorded on magnetic tape. The presently standardized 0-10 MHz ionogram requires the storage of 21600 characters. Transmission via telephone line has been accomplished requiring 2 seconds per frequency for a total of 3 minutes 20 seconds for the ionogram shown.

THE GEOMONITOR

In order to reduce the requirements for tape, prepare the data for automatic analysis and limit the amount of data to be transferred by data links to remote users, digital techniques of echo recognition were developed and implemented in the Geomonitor. Microprocessor controlled special electronic circuits achieve the high speed required for the simultaneous processing and display of the digital ionograms and the continuous data stream from various geophysical sensors.

For the processing of the ionograms initially the noise level on each frequency is established. Strong spread F or auroral Es echoes could lead to an overestimate of the noise level, thus suppressing weaker echoes. To circumvent this problem the noise level is determined separately for the lower and the upper 64 height bins by calculating the amplitude distributions for both ranges; the distribution which peaks at a lower amplitude is used to determine the noise level. The noise threshold is set at the positive half point of the distribution and only amplitudes larger than this level are considered as possible echoes. The noise threshold itself is recorded for reference.

The echo detection algorithm scans the 128 height bins on each frequency and detects up to six echoes, two from the E-region (<156 km) and four from the F-region. The selection of echoes is by average pulse amplitude, separately for the two regions. For two different echoes to be recognized as such they must be separated by a dip in amplitude down to the noise threshold. The echo spread is an important parameter in the assessment of the degree of disturbances, and it strongly influences the determination of ionospheric parameters such as foE and foF2. The Geomonitor determines and records, therefore, the spread of the main E and the main F echo.

The accurate heights of the leading edges of all six echoes is determined by sliding a standard pulse along an array of amplitudes with twice the resolution of the initial height steps. The exact virtual height of the echo is found at the position, where the average deviation (Bevington, 1969) between

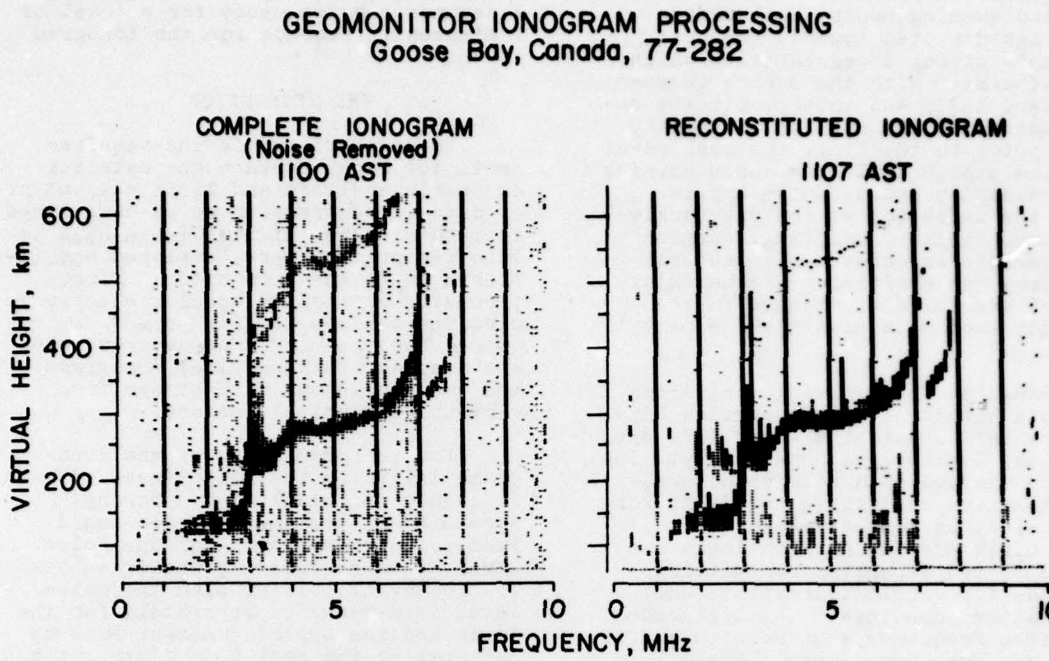

Figure 2. Geomonitor Ionogram Processing

standard pulse and (normalized) data is a minimum. The double-resolution array is generated by linear amplitude interpolation between two adjacent original height bins.

Finally, to investigate the dynamic height variations of the ionospheric layers, the Geomonitor calculates the so-called integrated heights. For each of the 128 height-bins the amplitudes are summed over all frequencies and normalized. This presentation was especially developed for use in the presentation of ionospheric characteristics to be discussed later.

The complement of data, with the addition of the gain setting on each frequency and the housekeeping information, for a standardized total of 128 frequencies, is collated or formatted into one digital record of 2340 characters, a reduction to about 10% of the original data. Evaluations have shown, that the chosen parameters and the number of echoes adequately depict an original ionogram for all routine and most special investigation purposes even under very disturbed conditions. The data are in a format perfectly suited for further processing, as the online determination of critical frequencies, the minimum frequency, layer heights and true height analysis. All these parameters can be determined using minimum computational effort. The development of the techniques to be applied is underway and will be concluded within the near future.

For verification of proper performance of the algorithms the collated ionograms described above are recast into the format of a regular Digisonde ionogram and presented on various displays. Shown in the right section of Figure 2 is such a "reconstituted" ionogram, taken 7 minutes after the one on the left, which is an unprocessed "cleaned" ionogram with amplitudes smaller than the noise level (see above) removed. The example is typical for the performance of the presently used algorithms. The high quality of the reconstituted ionogram is evident, minor problems as raggedness of the spread width will be corrected by refining the respective algorithms.

Sandwiched between the collated ionograms are the so-called "Geophysical Data", also packaged in a 2340 character long record representing 5 minutes of data. Analog signals from the three magnetometer channels, two riometers, satellite signals for Total Electron Content (TEC) and amplitude scintillation measurements are digitized and recorded. Additional analog

data up to a total of 15 can be added as required. Digitization rates presently used are 2 Hz for two scintillation channels and 0.1 Hz for the remaining 13 channels.

In its present operation the Geomonitor produces every five minutes one record of geophysical data and two records for two ionograms of various types (vertical, backscatter, coherent or power integration) as selected at the Digisonde. Reduced operation as, for example, quarter hourly ionograms only is readily possible. The data load of 3 × 2340 or 7020 characters/5 min can be handled by available 600-1200 baud telecommunications links.

DATA PRESENTATION

An important requirement for the analysis of multi-dimensional data under all conditions, but especially important for real time applications, is intelligent presentation that reveals the characteristics of the data set. In the case of ionogram observation, it is the original ionogram itself that gives the scientist the most detailed answer in regard to the momentary conditions of the ionosphere. It does not show, however, the time development of the ionospheric parameters, i.e. the diurnal variations and disturbances, unless a sequence of ionograms is studied simultaneously. Analog methods to present characteristic ionospheric parameters as a function of time, like the critical frequencies of E and F-region and the layer heights, were developed in the fifties (Nakata et al, 1953; Bibl, 1956). Since 1969 Digisondes have produced digital ionograms and we have developed computerized techniques to generate digital characteristics. Use of microprocessor technology in the Geomonitor has made it possible in Goose Bay to print out digital ionospheric characteristics in real time. To extend the usefulness of the display techniques to other users, a Geomonitor Display System which is close to completion, can take the Geomonitor data stream, as arriving via any suitable data link, and present these data in the form of characteristics, and as reconstituted ionograms at any remote site.

Figure 3 is a typical example of three selected characteristics. Shown on top are the integrated heights and ranges derived from backscatter ionograms, below, the F-region characteristic and at the very bottom the E-region characteristic of the vertical incidence ionograms. Each ionogram produces one line in each characteristic.

The height or range characteristic is produced by simply printing out the 128 characters available in each ionogram record, which result from the summation of amplitudes over all frequencies for each height bin separately. Since the ionogram traces are almost horizontal at the minimum heights of the respective layers, the summation results in large numbers at these heights. Similar properties of oblique, oval associated backscatter echoes, result in strong integrated amplitudes at the range of these echoes. Range or height changes with time are thus visible at a glance in this characteristic.

The F-layer characteristic is obtained by sequentially printing the largest of the four F-echoes amplitudes into the respective frequency bin. The presentation thus obtained is an amplitude and frequency vs. time history and, as time progresses, reflects the changes of upper and lower limit of the frequency band reflected from the F-layer. The lower limit is generally a function of occulation by the lower E-layer or of enhanced absorption. The upper limit and its time variation is in daytime a direct measure of the foF2 (the Digisonde uses circularly polarized antennas that suppress the extraordinary component). Spread-F conditions routinely observed at night at Goose Bay make the upper limit a more complicated parameter of the degree of F-region disturbance.

The E-layer characteristic shown in the lowest panel is obtained in an identical fashion by printing the larger amplitude of the two E-echoes into the respective frequency bin. The upper limit of the band of strong amplitudes is equal to foE in those time sectors, where the cosinusoidal time variation shows the solar zenith angle control of the E-ionization. At other times, sharp spikes or deviations from a smooth daytime E-ionization indicate the presence of Es with ftEs > foE.

The daily variations of foF2, foE, h'F and backscatter characteristics for the Goose Bay ionosphere are evident on these hard copy time histories. Comparison with variations of the previous days and with easily produced average curves allows the assessment of current trends as for example enhanced or depressed foF2. The range of auroral backscatter at a given hour in the afternoon or evening can be converted

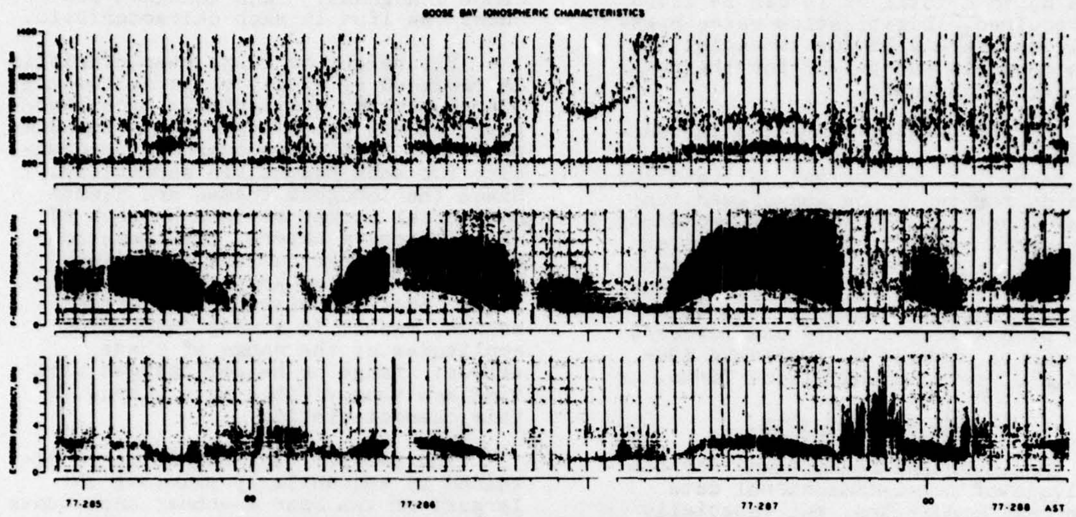

Figure 3. Goose Bay Ionospheric Characteristics

into a specific Q-value. Well established knowledge of oval continuity (Buchau et al, 1970) and the prediction of the circumpolar location of discrete auroral forms (Meng, 1977) from a locally established Q-value makes these backscatter range determinations a powerful measurement. The "anchor point" technique of using a one-point measurement to predict the whole oval has been developed by Gassmann (1973) and is at present successfully used at AFCWC with satellite auroral images providing the input parameter Q_E, the equatorward oval boundary. Of special importance is the ability, to interpret various types of signatures in the characteristics as evidence of auroral oval and ionospheric disturbances. Examples of such signatures are increased minimum frequency resulting from an increase in D-region electron density, the time history of such an increase, the existence of total absorption, sporadic E events, strong spread F occurrence, the sudden depression of foF2, and the early appearance or the rapid advance of backscatter fronts.

The parallel display of properly formatted Geophysical Data provides insight into the nature of the disturbance from different points of view and has to be made an integral part of the assessment of the event prior to issuing of an event report. As the disturbance grows in intensity, ionospheric characteristics become more difficult to interpret either due to the general lack of clear patterns found especially during magnetic storms or due to the strong increase in auroral absorption resulting in total lack of ionospheric echoes. Under these conditions the measurements most important to the preparation of advisories are the riometer and the magnetometer measurements.

The following discussion of the possible real time use of the Geomonitor and Display System in support of an Over-the-Horizon Backscatter Radar (OTH) System operating in this environment demonstrates the approach. The discussion also shows on examples the signatures of specific events and the value of the data compression and characteristic presentation to the investigation of ionospheric phenomena in general.

Let us consider the OTH radar located at a midlatitude location with Goose Bay within the surveillance area. (This is actually the situation of the planned 414L CONUS OTH-B Experimental Radar System, which is scheduled to start tests in 1980 and which will receive Goose Bay Ionospheric Data.) The latitude dependent ionospheric features associated with the auroral ionosphere such as the F-layer trough and the trough wall location, and the time dependent disturbances, such as absorption and sporadic E all have strong impacts on the propagation situation. Limitation of coverage, multipath to one target and azimuth/range errors due to the large gradients are but a few of the related problems.

Assume a station like GBIO with a Geomonitor connected by a communication link to the Geomonitor Display System located in the radar system operations

center. The GDS then provides a comprehensive ionospheric and geophysical data display for use by the radar's ionospheric forecaster. The forecaster assists the radar operators in the frequency management and in determining whether and how the radar is being affected by natural disturbances over part or all of the surveillance area. He also estimates the probability of the disturbance subsiding or continuing. Figure 4 shows a vertical incidence reconstituted ionogram from GBIO at 1000 local time on day 286. An absorption condition exists and only fragments of echoes from the usual daytime layers are seen. More information is available from the characteristics in Figure 3. They show no absorption on this day prior to the event onset and during the previous night. Such time history is indicative of a localized absorption event drifting around from a nightside auroral substorm, and it is likely to be of short duration. The ionospheric forecaster would advise the operators to this effect. Looking at the characteristics at later times that day, we see that the absorption did indeed diminish, disappearing completely in 2 or 3 hours. The ionogram (Figure 5) shortly afterward at 1307 local time on day 286 shows the expected daytime ionospheric layers indicating normal radar system operation.

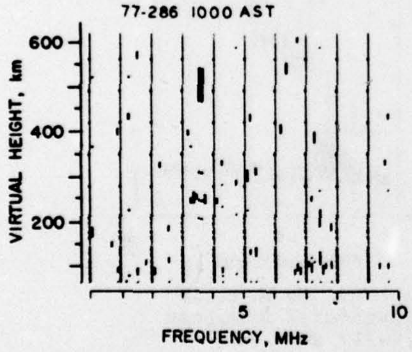

Figure 4. Geomonitor
Reconstituted Ionogram
77-286 1000 AST

The vertical incidence ionogram at 0930 local time on day 292 is quite similar to Figure 4, showing complete absorption. The characteristics in Figure 6 show that the E layer echoes had been absorbed throughout the morning, and that absorption had occurred periodically during the previous night; a high level of disturbance is evident

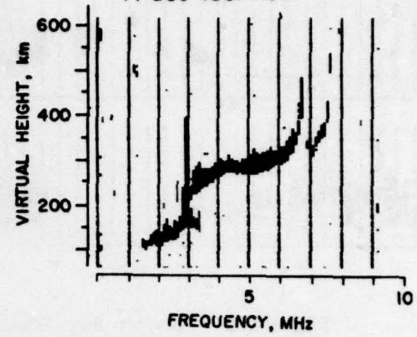

Figure 5. Geomonitor
Reconstituted Ionogram
77-286 1307 AST

in the rapid changes in the Es top frequency. This suggests that disturbed conditions will continue with the resulting disturbing effects on the radar system. The ionospheric forecaster would advise the operator on expected future problems. This would permit enhancement of other available means of surveillance if extended outages could not be tolerated. The characteristics later in the day continue to show complete absorption as was inferred above. During short periods, when the absorption subsides, foF2 can be determined as 5.5 MHz, compared to 6.8 MHz on day 286 at the same time. This depression supports the assessment of a continuing disturbance, and aids the frequency management during times when propagation is possible.

The ionogram in Figure 7 shows a typical late afternoon ionosphere at 1637 AST on day 287 with an foF2 of 8.7 MHz. HF propagation would be by F-layer modes. Examination of the backscatter ionogram range characteristic shows that echoes which are associated with the auroral oval have been present as early as 1530 AST with decreasing range throughout the next hours. This indicates that the auroral oval was expanded and that the observatory and thus the OTH coverage area would rotate under the oval early in the evening. The ionogram at 1800 AST in Figure 8 verifies the prediction. The Es layer is well developed, the presence of an Es multiple indicates that absorption is not strong. Thus for selected azimuths, HF propagation would be by E layer modes only. Knowledge that the propagation has changed from F-layer to E-layer modes is impor-

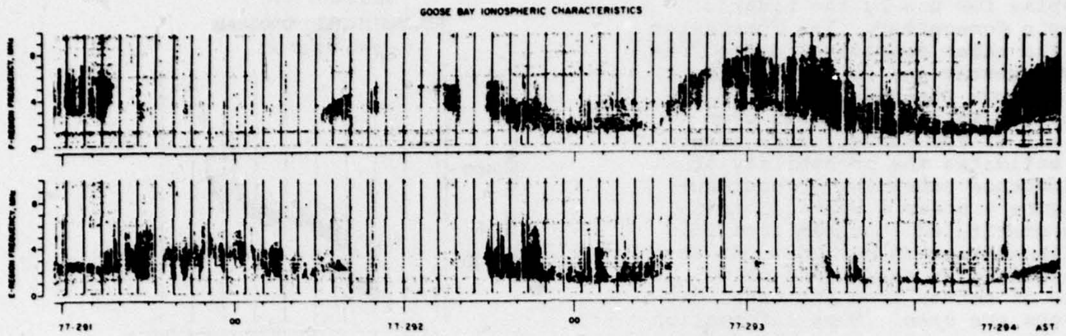

Figure 6. Goose Bay Ionospheric Characteristics, disturbed period

tant in interpreting the range of targets in the surveillance area. The characteristics show that the Es event continued for several hours. Figure 9 shows that the Es reached 10 MHz at 2052 AST allowing for the use of rather high surveillance frequencies but providing only short (<2200 km) range coverage in the general direction of Goose Bay.

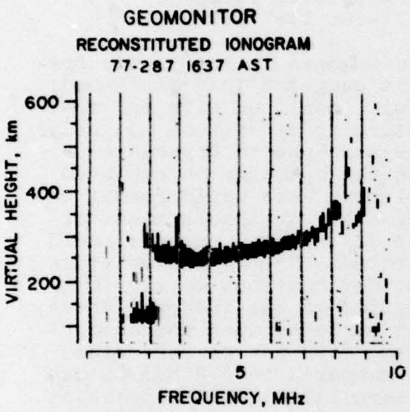

Figure 7. Geomonitor Reconstituted Ionogram 77-287 1637 AST

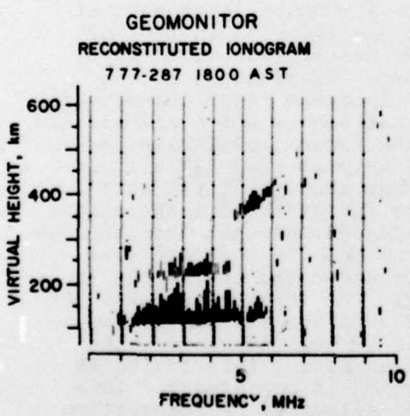

Figure 8. Geomonitor Reconstituted Ionogram 77-287 1800 AST

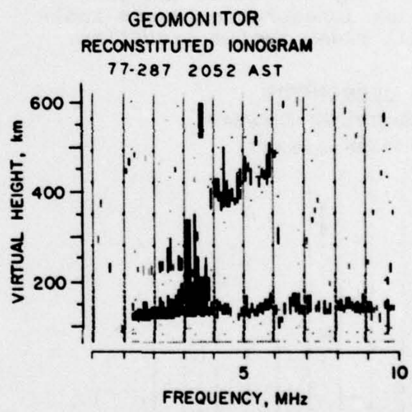

Figure 9. Geomonitor Reconstituted Ionogram 77-287 2052 AST

Another type of behavior of the ionospheric features associated with the auroral ovals occurred on the night of day 286. The backscatter range characteristic showed that the oval stayed well poleward of GBIO throughout the night. The ionogram at 2345 AST in Figure 10 showed the off-vertical echoes from the oval appearing in the vertical ionogram display. The foF2 at this time was approximately 2 MHz, indicating GBIO and thus a large part of the coverage area was in the midlati-

tude ionospheric trough. Knowledge that the auroral oval stayed poleward of Goose Bay and that GBIO was underneath the trough is informative in evaluating the ionosphere effecting the radar surveillance area equatorward of Goose Bay. The reconstituted ionogram at this time would be very important input to the coordinate conversion conducted by the radar to convert azimuth and range information into target ground coordinates, dependent on the reflecting height of the ray path.

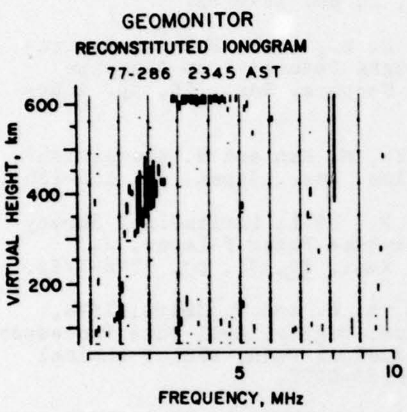

Figure 10. Geomonitor Reconstituted Ionogram 77-286 2345 AST

Notice the contrast in the size of the auroral oval on days 286 and 287. On 286 it remained poleward of GBIO all night, indicating a Q index value of 0. On 287 it arrived overhead at 1800, consistent with a Q index of 8.

SUMMARY

We have described an approach to the remote monitoring of the high latitude ionosphere, which is summarized in Figure 11. Digital vertical incidence and backscatter ionograms are reduced in the Geomonitor by extracting amplitude, height and spread of the ionospheric echoes. The algorithm works remarkably well even under disturbed conditions during an auroral event. Properly formatted digitized magnetometer, riometer and satellite propagation data and the processed ionospheric data are stored on tape, or for real time use, are transmitted over a suitable medium capacity data link to any desired user site. Here a Geomonitor Display System separates the data, presents them as characteristics or time histories of various ionospheric parameters and of the geophysical data for interpretation by an observer. The usefulness to an OTH system has been shown on selected samples. Quiet day curves for the various geophysical data and thresholds for minimum frequency and Es-events can be used in the Geomonitor and the Display System to initiate alarms when deviations of predetermined magnitude occur.

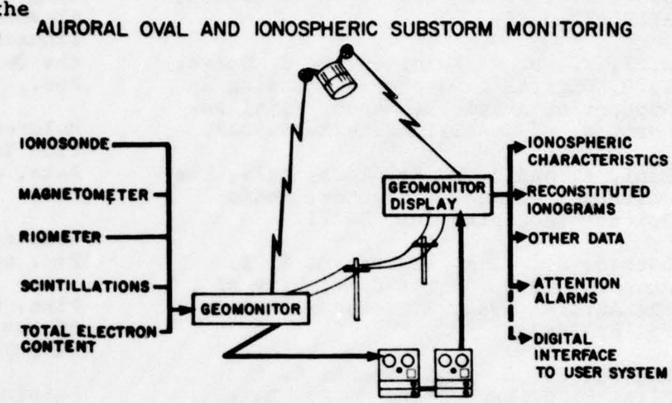

Figure 11. Schematic presentation of data requirements, data flow and display for remote oval monitoring.

The addition of two more monitor sites, one in the European Arctic and one in Alaska could provide inputs into AWS-SESS resulting in a 24 hour continuous coverage of all high latitude disturbances and the continuous determination of the location of the boundary between F-layer trough and auroral oval. Together with the sporadic DMSP satellite auroral images, complete and continuous understanding of the state of this important section of our environment can be achieved. The U. S. Army employs an instrument (Automatic Ionogram Collator) similar to the Geomonitor for their Digisonde operation in Fort Monmouth, N.J. (F. Gorman, private communication). This system could offer the possibility of a mid-latitude expansion of the arctic network.

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